Effect of Polyethersulfone Molecular Weight on Structure and Performance of Ultrafiltration Membranes

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Polyethersulphones (PES) with three different molecular weights were chosen to prepare ultrafiltration (UF) membranes by the nonsolvent induced phase separation method using polyvinylpyrrolidone (PVP) and N-methyl-2-pyrrolidone (NMP) as additive and solvent, respectively. The effect of PES molecular weight on the structure and performance of the prepared asymmetric membranes was investigated by means of UF experiments, measurements of membrane thickness and porosity, scanning electron microscopy, and the measurement of bursting strength, given fixed PVP or PES concentrations. It was found that increasing PES molecular weight would lead to a larger pore size in the skin layer but lower membrane porosity, and would result in membranes with higher strength, higher permeability, and lower rejection. Based on the experimental data of PES molecular weight, ternary phase diagram, and cast solution viscosity obtained from gel permeation chromatography, cloud point titration, and coaxial cylinder viscometer measurements, respectively, the underlying causes of membrane structures were accounted for from the combined perspective of thermodynamics and kinetics and polymer aggregate dimensions.

1. Introduction

Thanks to its membrane-forming properties and mechanical and chemical stabilities, polyethersulfone (PES) is frequently used for preparing ultrafiltration (UF) membranes. PES membranes are found to be of great potential for application in such fields as biotechnology, pharmacology, and water treatment. Extensive studies have been carried out on how the PES membrane structure and properties are impacted by a variety of parameters, such as the compositions of the polymer solution or the environment, air moisture, temperature of polymer solution or the nonsolvent or the mixture of nonsolvents,† the preparation conditions,9–11 which include the temperature of the polymer solution or the coagulation bath (the nonsolvent or the mixture of nonsolvents), the ratio of bovine serum albumin increases.16 Bil’dyukevich et al. claimed that, with the growing content and molecular weight of PES, the water flux of membrane reduces and the retention ratio of bovine serum albumin increases.16

In the limited literature, conflicting results have been reported. Miyano et al. found that the average pore size at the surface layer of asymmetric polymeric membranes increases with an increase in polymer molecular weight and with a decrease in polymer concentration.15 It should be pointed out that in the study PES–pure solvent cast solutions were used to produce membranes, which is far from real application where additives are indispensable in preparing asymmetric membranes. In contrast, Zhao claimed that, with the growing content and molecular weight of PES, the water flux of membrane reduces and the retention ratio of bovine serum albumin increases.16 Bil’dyukevich et al. stated that hydraulic permeability increases and selectivity goes through an extreme peak with decreasing molecular weight of PES.17 In addition, little research data are available about the effect of PES molecular weight on the membrane structure in these three papers.

Therefore, further study is still needed to gain a clearer and more comprehensive understanding of the effect of polymer molecular weight on the membrane structure and properties. For this purpose a systematic experiment was designed in our
study. PES of three different molecular weights, determined with gel permeation chromatography (GPC), was selected as the membrane material. The cast solution with N-methyl-2-pyrrolidone (NMP) as the solvent and polyvinylpyrrolidone (PVP) as the nonsolvent additive, which is most representative in PES UF membrane preparation, was adopted. The nonsolvent induced phase separation method (NIPS) was used to prepare the membranes. Ternary phase diagrams of the membrane-forming systems and viscosity data of the cast solutions were used to characterize the thermodynamics and diffusion kinetics of the systems. The ternary phase diagram of the PES/NMP/water cast solution system was constructed based on cloud point titration. The viscosity of cast solutions was studied with a coaxial cylinder viscometer. UF experiments were used to evaluate the permeability of membranes. Based on the above data, the formation of a skin layer structure of membranes was deduced. The sublayer structure of membranes was investigated by means of thickness measurement, porosity analysis, and scanning electron microscopy (SEM). Finally, the pressure resistance was analyzed by the measurement of bursting strength.

2. Experimental Section

2.1. Materials. PES from Jilin University, China, and PES BL-4 and BL-5 from Beishide Chemical Co., China, were used. They were dried in an oven at 80 °C for at least 20 h before use. NMP, PVP K30, and polyethylene glycols (PEG) with nominal molecular weights of 1, 6, 10, 20, and 35 kDa were purchased from Sinopharm Chemical Reagent Co. Ltd. Water purified with a Milli-Q system from Millipore was used for all experiments.

2.2. Molecular Weight Measurement. As detailed information of the PES molecular weight is usually not readily available with purchase, measurement is needed to obtain such data. The molecular weight and molecular weight distribution of PES samples were measured by GPC (TOSOH Co. Japan) with a refractive index detector. Column sets of AW3000 and AW5000 were used. N,N-Dimethylformamide containing 0.05 mol/L lithium bromide was used as the eluent at a flow rate of 0.6 mL/min at 40 °C. For calibration, polystyrene standards were applied. The number-average molecular weight (Mn), weight-average molecular weight (Mw), and polydispersity index (Mw/Mn) were calculated using the calibration curve obtained from the standard samples of monodisperse polystyrene.

2.3. Ternary Phase Diagram Construction. The ternary phase diagram was constructed from the cloud point titration data. The cloud point curve was determined by the usual titration method, in which polymer solutions with different concentrations of PES in NMP were prepared by mixing desired amounts of these materials in sealed glass bottles. A homogeneous polymer solution was obtained by magnetic stirring for 72 h. To perform the titration, pure water with 0.05 mL accuracy was dropped constantly into the polymer solution under agitation. During titration, the solution temperature was controlled at 20 °C. The addition of pure water continued until the clear polymer solution turned cloudy visibly. At the first sign of turbidity, the addition of water was stopped and the cloudy solution was agitated for an additional 30 min to see whether the turbid solution would become clear. In the former case, more water was added; otherwise the cloud point was recorded. The composition at the cloud point was then determined by the amount of water, NMP, and PES present in the bottle.

2.4. Viscosity Measurement. The cast solution viscosity was measured with a rotational rheometer (Advances Rheology Expanded System, TA Instruments, Twin Lakes, WI) in coaxial cylinder geometry. The temperature of the unit was controlled at 23 °C by a circulating water system. The cast solution was placed in the cylinder and sufficient time was allowed for it to reach thermal equilibrium. The shear stress was determined in a range of shear rates up to 100 s⁻¹.

2.5. Membrane Preparation. PES membranes were prepared by the NIPS method. PES and PVP were dissolved in NMP by stirring at 70 °C to form a homogeneous cast solution. The composition for the cast solution is represented by PES/PVP/NMP in terms of the mass percentage ratio. The solution was then cast at room temperature (23 °C) on a glass plate by using a casting knife with the thickness of the cast film maintained at 0.25 mm. The humidity was controlled at about 30%. The cast film was exposed to air for 30 s and then immersed into a water bath at 18 °C. After gelation, the membrane was stored in deionized water until it was tested.

2.6. Ultrafiltration Experiments. The UF membranes with an effective area of 35.3 cm² were characterized by using a dead-end filtration cell with a stirring speed at 300 rpm. The experimental setup to measure the pure water flux, solute flux, and solute rejection is presented in Figure 1. The membranes were kept in deionized water at 0.1 MPa for 10 min until the pure water flux was tested. PEG aqueous solutions with a concentration of 0.5 g/L were used for measuring the solute rejection (R) at 0.1 MPa and room temperature for 20 min after the system was running.

Pure water fluxes and solute fluxes were obtained according to the following equation:

\[ J = \frac{Q}{(\Delta T)A} \]

where \( J \) is the permeation flux (L m⁻² h⁻¹), \( Q \) is the volume of the solution permeated (L), \( \Delta T \) is the sampling time (h), and \( A \) is the effective membrane area (m²).

The rejection was calculated by the following equation:

\[ R = 1 - \frac{C_p}{C_f} \]

where \( C_p \) and \( C_f \) are the concentrations of the probe solute in permeate and feed, respectively. \( C_p \) and \( C_f \) were determined from the total organic carbon (TOC) measured by using a TOC analyzer (Shimadzu TOC-5000A).

2.7. Membrane Thickness Measurement. The membrane thickness was measured by using a digital micrometer (211-101EK, Guilin Guanglu Measuring Instrument Co. Ltd.).
is worth mentioning that in Miyano’s paper only molecular weight has a wider molecular weight distribution. It samples is less than 2.5 and that PES with a higher average where

\[ P = \frac{W_0 - W_1}{Ah} \times 1000 \]

where \( P \) is the membrane porosity (%), \( W_0 \) is the wet sample weight (g), \( W_1 \) is the dry sample weight (g), \( A \) is the membrane area (cm²), and \( h \) is the membrane thickness (mm). Five membrane samples were measured for obtaining the average value.

2.8. Porosity Measurement. The membrane porosity was measured according to the literature. The membrane from deionized water was weighed after its surface water was absorbed by filter paper. The wet membrane was dried in a vacuum oven at 80 °C for 24 h before it was weighed. From the two weights (wet sample weight and dry sample weight), the membrane porosity was calculated using the following equation:

\[ \text{Porosity} = \frac{W_0 - W_1}{W_1} \times 100 \]

2.9. Scanning Electron Microscope. The images of the cross sections of prepared membranes were obtained with SEM (LEO1530vp, Germany). For this purpose, the membranes were frozen in liquid nitrogen and then broken into pieces, which were transferred into the microscope chamber with a sample holder after sputtering with gold as the conductive material.

2.10. Bursting Strength Measurement. The bursting strength instrument is schematically shown in Figure 2. The membrane with an area of 8.0 cm² was installed in the instrument and subjected to increasing pressure until the membrane was broken, when the pressure was recorded. A larger pressure represents a larger bursting strength.

3. Results and Discussion

3.1. PES and PES Cast Solutions. 3.1.1. PES Molecular Weight. In this study PES samples from a number of suppliers were measured by GPC, and three PES polymers with considerable differences in molecular weight were selected to be the materials for membrane preparation, whose \( M_n, M_w, \) and \( M_w/M_n \) are listed in Table 1.

It can be found that the polydispersity index for all three PES samples is less than 2.5 and that PES with a higher average molecular weight has a wider molecular weight distribution. It is worth mentioning that in Miyano’s paper only \( M_n \) was made available regarding PES molecular weight, which was 40.5, 50.3, and 55.8 kDa, respectively (according to the author, the values were higher than the real ones), while in Zhao’s paper the PES average molecular weight was 56, 69, and 82 kDa, respectively, without indication of \( M_w \) or \( M_n \).

For the sake of clarity, in the following discussions PES42, PES65, and PES120 are used to represent PES with molecular weights of 42, 65, and 120 kDa, respectively.

3.1.2. Ternary Phase Diagram. A ternary phase diagram was used to measure the thermodynamic stability of the casting system. The binodals in three PES (PES42, PES65, and PES120) systems were determined by the titration method, as shown in Figure 3. It can be found that, for PES with higher molecular weight, the binodal curve of the corresponding PES/NMP/water system is closer to the polymer–solvent axis, which means less water is needed for the precipitation of this system. This indicates that the higher PES molecular weight, the lower thermodynamic stability of its cast solution.

3.1.3. PES Cast Solution Viscosity. The viscosity of the membrane cast solution is an important factor for membrane preparation. It is believed to affect the solvent/nonsolvent exchange, the velocity of phase separation, and the gelation dynamics. Higher viscosity can inhibit the exchange rate of solvent and nonsolvent during the phase inversion process, which in turn affects the precipitation kinetics and thus the formation of membrane morphology. It is commonly acknowledged that PES membranes prepared from low viscosity cast solutions are not ideal membranes regarding mechanical strength and handling. Usually higher viscosity is required in order to prevent excessive solution penetration into the porous supporting materials for flat-sheet membranes and to produce mechanically resistant fibers.

Figure 4 shows the shear viscosities of the PES cast solutions. It is found that all cast solutions exhibit characteristics of Newtonian fluids in the range of shearing rates of the viscometer. These results are in agreement with the literature, according to which the PES/NMP cast solutions in a wide range of PES concentrations up to 38 wt % behave as Newtonian fluids. In addition, the presence of PVP does not change the Newtonian characteristics of the cast solution. In other words, there is no or little chain entanglement in these solutions.

The effect of PES molecular weight on the viscosity of cast solutions can be found in Figure 4. For any given PES or PVP concentration, the viscosity increases with PES molecular weight.

Comparing Figure 4a with Figure 4b and Figure 4c, it can be found that, for a given PES molecular weight, the viscosity
increases with the increase of PVP concentration, which is in agreement with the literature.\textsuperscript{3,23} The higher viscosity caused by increased PVP concentration indicates the presence of larger size supermolecular polymer aggregates in the solution. Both factors, the higher PVP molecular weight than that of NMP and the inter- and intramolecular aggregations formed in the presence of PVP, contribute to the increase in viscosity.\textsuperscript{4}

A comparison between Figure 4c and Figure 4d shows that, for a given PES molecular weight, with enhancing PES concentrations the viscosity increases. Such an increase is more considerable for PES with a higher molecular weight. For example, at a composition of 15/5/80, the viscosity of PES120 solution is 10 times more than that of PES42 solution, while at a composition of 20/5/75, the corresponding viscosity difference is 20 times more. This might be explained by that a polymer with larger molecular weight has a larger globule size in the solution.\textsuperscript{15}

3.2. Membrane Permeation Performance. 3.2.1. Flux and Rejection.

To study the effect of PES molecular weight on membrane permeability under different conditions, membranes prepared from two sets of compositions were characterized. For the first set, three series of compositions were chosen: PES concentrations of 15\%, 18\%, and 22\% with fixed PVP concentration of 5\%, respectively.

Figure 5a and Figure 5b display the results of UF experiments performed with pure water and PEG20000 aqueous solutions. It can be found that, as PES molecular weight increases, both the pure water flux and PEG20000 flux increase, with the latter smaller than the former, while the rejection decreases. It can also be found that, with the same cast solution composition, the permeate flux of membranes varies considerably from low to high PES molecular weight. Take the composition of 18/5/77, for example: for PES42 and PES120 membranes, the pure water flux changes from 6 to 124 L m\(^{-2}\) h\(^{-1}\). Such a finding is of great significance in membrane preparation in that, for the same cast solution composition, polymers with different molecular weights would lead to noticeable differences in membrane performance.

Comparison of the flux for membranes with the same PES molecular weight but different PES concentrations reveals that a higher polymer concentration of the cast solution results in a lower flux, which is consistent with related literature.\textsuperscript{3}

For a polymer/nonsolvent additive/solvent system, the nonsolvent content is another important factor for membrane performance. To study the effect of PES molecular weight on membrane performance at different PVP concentrations, the second set of membranes were prepared according to the following compositions: fixed PES concentration at 20 wt \% with PVP concentrations of 1, 5, and 10 wt \%, respectively. The membranes were then characterized using UF experiments with the same procedures as described above. The results are presented in Figure 5c and Figure 5d.
From Figure 5c,d, it can be observed that for a given PVP concentration the effect of PES molecular weight on membrane permeability coincides with the previous results in the study; i.e., as PES molecular weight increases, both the pure water flux and PEG20000 flux increase, with the latter smaller than the former, while the rejection decreases. However, the higher the PVP concentration, the more remarkable the effect of PES molecular weight on performance, and the larger the deviation of membrane permeability.

For a fixed PES molecular weight, the flux increases with the PVP concentration while the rejection decreases, which is in agreement with the literature. Furthermore, the larger the PES molecular weight, the bigger the difference.

3.2.2. Rejection Profile. The molecular weight cutoff (MWCO) is one of the most important specifications to describe the retention capabilities of UF membranes, and it refers to the molecular weight of a solute (typically, PEG or dextran) for which a given membrane has a retention capability greater than 90%. The MWCO can be defined by the rejection curve obtained from plotting rejection of solutes versus their molecular weight, which is of the sigmoid shape generally. Figure 6 shows the rejection curves of the membranes prepared from three cast solution compositions: (a) 15/5/80, (b) 20/5/75, and (c) 20/10/70, respectively.

It can be inferred that, for a given composition, the MWCO tends to increase with the PES molecular weight. It can be concluded that, for a membrane prepared from PES with a lower molecular weight, the selectivity is better than that from PES with a higher molecular weight. The rejection curve can also be used to estimate membrane pore size, for a larger MWCO is believed to correspond to a larger pore size.

As is well recognized, the separation properties of asymmetric membranes are affected by pores in their skin layers. The above results could be used to deduce the effect of PES molecular weight on the formation of skin layer structure.

In general, the formation of skin layer could be described as follows: upon immersion of the cast polymer solution in the nonsolvent water bath, the fast solvent/nonsolvent exchange across the interface, combined with the large repulsive forces between PES and water (water is a very powerful nonsolvent for PES), causes immediate precipitation of the polymer at the interface. This process is too fast for any segregation of the polymer solution into the polymer-rich phase and the polymer-poor phase. As a result, a thin skin consisting of closely packed spheres or nodules starts to form. A nodular structure is often present in UF membranes. The formation of the skin layer agrees with the spinodal decomposition mechanism, and the thermodynamic factor plays the leading role. Faster solvent/nonsolvent exchange signifies rapid solidification of the polymer aggregates, forming less tightly packed arrays of nodule aggregate with larger pores in the final membrane and more open pore channels. Slower exchange signifies gradual solidification of the polymer aggregates forming more tight aggregate pores and narrower pore channels. On the other hand, the size of the polymer aggregates, as qualitatively indicated by the viscosity data, also determines, to a significant extent, the ultimate pore structure of the membranes.

PES molecular weight influences the formation of skin layer structure from the following aspects. A higher PES molecular weight would lead to a faster solvent/nonsolvent exchange resulted from lower thermodynamic stability of its cast solution, and to larger polymer aggregates size in the cast solution, which in turn would cause formation of larger pores. However, for PES with higher molecular weight, the viscosity of its cast solution was higher than that with low molecular weight at the same composition. High viscosity would slow the exchange.
between solvent and nonsolvent in the phase separation process, resulting in the decrease of pore sizes. The UF experiment results indicate that the thermodynamic stability and the polymer aggregate size are dominating factors under the conditions of this study.

3.3. Membrane Structure. 3.3.1. Membrane Thickness. During its formation by immersion precipitation, a membrane typically shrinks upon gelling, with a loss of about 20–80% of its thickness. As thickness is impacted by a number of factors during the membrane formation process, e.g., the composition and temperature of the cast solution, the duration of exposure to the gaseous environment, and the relative humidity of the air during exposure, trends about the thickness change can provide clues to the formation of membrane structures.

Figure 7a shows the effect of PES molecular weight on the membrane thickness at fixed PVP but different PES concentrations, and Figure 7b shows the effect at fixed PES but different PVP concentrations. It can be found from these two figures that, for a given cast solution composition, a higher PES molecular weight would result in a lower thickness of membranes and vice versa. A couple of minor irregularities could be attributed to the variability in membranes, which can be significant in membrane preparation, even within the same batch of membranes.29

Figure 7a also indicates that, for a given PES molecular weight, higher PES concentrations would lead to thicker membranes, while Figure 7b shows that 5 and 10 wt % PVP concentrations correspond to thicker membranes than 1 wt % PVP concentration does, with little variation in the membrane thickness between the former two.

The above phenomena can be interpreted with the phase separation mechanism during the immersion precipitation. In other words, the membrane thickness is determined by the phase separation of the cast solution. There are two dominating factors controlling the formation of phase inversion membranes: thermodynamics and kinetics, correlated with each other in a system during the solidification of the cast solution. The former is related to the phase equilibrium between components in the system, and the latter is related to the mutual diffusivities between them.20 It must be stressed that the phase separation of the solution is a result of both factors working together. Therefore, the membrane thickness depends on the domination of one factor over the other.

In terms of its effect on the membrane formation, increase in PES molecular weight is similar to the addition of hydrophilic polymer or the increase of polymer concentration.20,30 On the one hand, increasing PES molecular weight enhances thermodynamic instability, which favors enhancement of phase separation in the cast solution. On the other hand, increasing PES molecular weight induces the increase in solution viscosity, which in turn causes kinetic hindrance against phase separation. In the case where the kinetic effect of viscosity increases or
the diffusion delay outweighs thermodynamic instability, the nonsolvent’s diffusion into the cast solution would be reduced, which results in lower thickness of the membranes obtained.

3.3.2. Membrane Porosity. The membrane porosity, as a crucial membrane property, can be manipulated by systematically varying membrane preparation parameters. Figure 8 illustrates the effect of PES molecular weight on the membrane porosity: Figure 8a under the condition of fixed PES but different PVP concentrations and Figure 8b under the condition of fixed PVP but different PES concentrations. It can be concluded that a larger PES molecular weight leads to a lower porosity. Increasing PVP concentration or decreasing PES concentration results in a higher porosity.

Comparing the results of porosity study with those of permeation performance, an interesting phenomenon can be found: for membranes prepared from the same composition, in spite of reduced porosity with increasing PES molecular weight, the permeation flux increases and rejection decreases. This further validates that, for an asymmetric membrane, the permeation performance is dominated by the structure of the skin layer.

The membrane porosity is related to the pore formation during the process of membrane forming by immersion precipitation, in which demixing occurs: a homogeneous polymer solution is separated by adding a nonsolvent through the solvent/nonsolvent exchange into two phases, i.e., the polymer-rich phase which forms the membrane structure and the polymer-poor phase which forms the pores in the final membrane. This process usually results in asymmetric membranes exhibiting a dense thin top layer (skin layer) and a porous sublayer. Since the sublayer is much larger than the skin and is mostly porous, the membrane porosity depends mainly on the sublayer structure, which is controlled by the demixing rate. In general, two types of demixing take place during the phase inversion process, i.e., instantaneous demixing and delayed demixing. According to the literature, membranes formed by instantaneous demixing generally show a highly porous substructure (with macrovoids) and a finely porous, thin skin layer. Membranes formed by a delayed demixing mechanism show a porous (often closed-cell, macrovoid-free) substructure with a dense, relatively thick skin layer. As discussed earlier, all three factors, i.e., addition of PVP, increase of PES concentration, and increase of PES molecular weight, would increase thermodynamic instability, which tends to favor instantaneous demixing, while enhanced solution viscosity tends to delay demixing. When thermodynamic instability prevails, the rate of solvent/nonsolvent exchange would be enhanced and more porous membranes would be formed. On the contrary, when the increase of solution viscosity kinetically slows the rate of solvent/nonsolvent exchange to a certain value, formation of pores would be suppressed.31
3.3.3. SEM Analysis. The microstructure and morphology of PES membranes prepared from three cast solution compositions (PES/PVP/NMP 22/5/73, 18/5/77, 15/5/80) were examined for visualization by using SEM.

Figure 9 shows the SEM images of the membrane cross sections, which display the expected typical asymmetric structure with a thin dense skin layer and a thick porous sublayer consisting of two types of macrovoids, fingerlike and irregular (described as channellike, tearlike, etc. in some papers32,33), and pore walls with dense spongelike structure. It can be found that for a given composition, with increasing PES molecular weight, the fingerlike macrovoids next to the skin layer become longer and less in number and fineness, while irregular macrovoids become less in size. For a given PES molecular weight, with increasing PES concentration, the fingerlike macrovoids to the skin layer become finer, longer, and more in number, while irregular macrovoids become less in size and the thicknesses of the walls between macrovoids increase. The difference in C1 and C2 in Figure 9 may not be that obvious, yet walls are more porous in C1. Nevertheless, an increase in PES molecular weight, similar to an increase of PES concentration, leads to reduced volume of the macrovoids. These results indicate that higher PES molecular weight or PES concentration would result in lower porosity, which is in agreement with the porosity analysis.

The formation of membrane morphology has been extensively studied. Either nucleation and growth or spinodal decomposition mechanism has been put forward to explain liquid–liquid demixing of a polymer solution. The formation of sublayer agrees with the nucleation and growth mechanism, and the kinetic factor plays the dominant role. It is generally accepted that increasing the solvent/nonsolvent exchange rate leads to the formation of more channellike and long fingerlike structures, and any change in the preparation parameters, which slows the rate of solvent/nonsolvent exchange, tends to produce a spongelike structure.32 By systematically changing the rate, e.g., increasing PES molecular weight, a series of intermediate structures can be obtained lying between the two extremes.

3.4. Bursting Strength. In addition to permeability, the mechanical strength to withstand high pressure is another desired characteristic of membranes. The bursting strength of membranes is adopted to evaluate the mechanical strength of membranes.
The effect of PES molecular weight on bursting strength is shown in Figure 10a, where the PES concentration is fixed and the PVP concentration varies, and Figure 10b, where the PVP concentration is fixed and the PES concentration varies. It can be concluded that a larger PES molecular weight leads to increased strength. Increasing PVP concentration or decreasing PES concentration results in a reduced strength. This might be attributed to the porosity of the corresponding membrane as discussed before in this study. It is generally accepted that the mechanical strength of a membrane is related to both the inherent strength of the membrane material (the larger the polymer molecular weight, the larger its mechanical strength) and the integrity of the membrane structure.  

4. Conclusion

PES with three different molecular weights is characterized by GPC. The ternary phase diagram of the PES/NMP/water cast solution system is constructed based on cloud point titration. It is found that increasing PES molecular weight enhances the thermodynamic instability of cast solution. The viscosity of the corresponding cast solutions was characterized by a coaxial cylinder viscometer. The cast solutions are found to behave as Newtonian fluids. The viscosity of the solution increases with increasing PES molecular weight, as with increasing PES or PVP concentration.

UF membranes are prepared using the NIPS method by fixing the PES or PVP concentrations in the cast solutions in order to investigate the effect of PES molecular weight on the membrane structure and performance by means of thickness measurement, porosity analysis, SEM, UF experiments, and bursting strength measurement. It is found that, with increasing PES molecular weight, the membranes present higher permeability but lower rejection. It can be concluded that increasing PES molecular weight would produce higher strength membranes with lower membrane porosity but larger pore sizes in the skin layer. In contrast, UF membranes prepared from conventional methods, i.e., by adjusting cast solution compositions or preparation processes, would exhibit larger pore sizes in the skin layer with higher membrane porosity. The findings in this study may shed light on optimizing preparations of desired UF membranes.

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